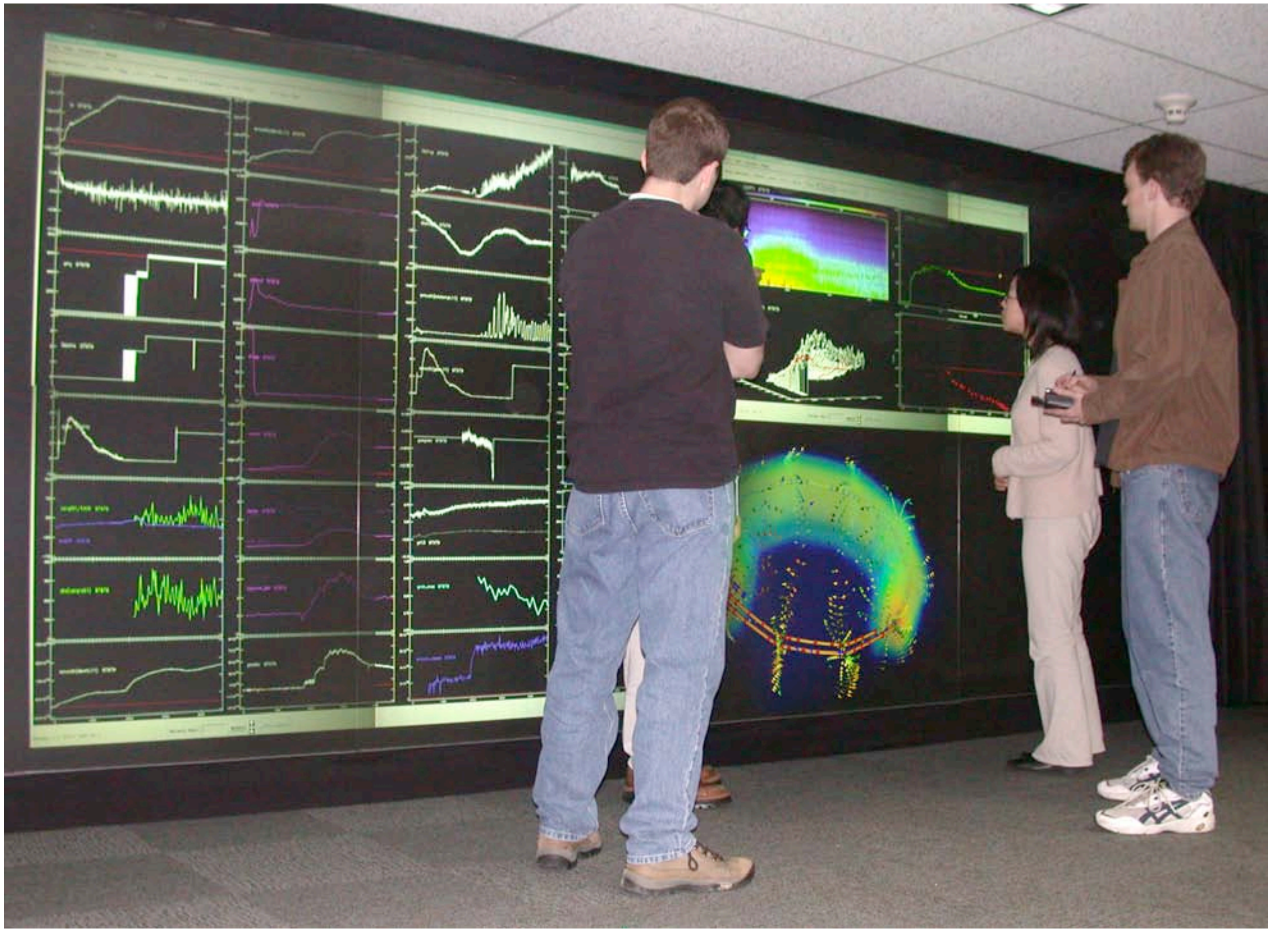
Anticipated Network Requirements For Magnetic Fusion Energy Science



Presented by
David P. Schissel

at
DOE Network PI Meeting
September 15-17, 2004
Fermi Laboratory

GENERAL ATOMICS

PRESENTATION’S KEY POINTS

- Magnetic fusion energy sciences is a worldwide effort
  - Next generation experimental devices will be outside the US
- Collaborative technology critical to the success of the FES program
  - Experimental: Fewer, larger machines in future (ITER, KSTAR)
  - Computation: Moving toward integrated simulation (FSP)
- A capable network & network service infrastructure is critical
  - More than moving bits around (1000 Mb/s)
  - Services over the WAN: Grids, QoS, security,

MFE RESEARCH IS WORLDWIDE

US Labs

ANL (Argonne, IL)
INEL (Idaho Falls, ID)
LANL (Los Alamos, NM)
LLNL (Livermore, CA)
ORNL (Oak Ridge, TN)
PNL (Richland, WA)
PPPL (Princeton, NJ)
SNL (Sandia, NM)

US Industries

CompX (Del Mar, CA)
CPI (Palo Alto, CA)
Creare (Hanover, NH)
Digital Finetec (Ventura, CA)
FAR Tech (San Diego, CA)
HiTech Metallurgical (San Diego, CA)
IR&T (Santa Monica, CA)
Orincon (San Diego, CA)
SAIC (La Jolla, CA)
Surmet (Burlington, MA)
Thermacore (Lancaster, PA)
TSI Research (Solana Beach, CA)

US Universities

Alaska (Fairbanks, AK)
Auburn (Auburn, Alabama)
Cal Tech (Pasadena, CA)
Colorado School of Mines (Golden, CO)
Columbia (New York, NY)
Georgia Tech (Atlanta, GA)
Hampton (Hampton, VA)
Lehigh (Bethlehem, PA)
Maryland (College Park, MD)
MIT (Boston, MA)
Palomar (San Marcos, CA)
New York U. (New York, NY)
Texas (Austin, TX)
UCB (Berkeley, CA)
UCI (Irvine, CA)
UCLA (Los Angeles, CA)
UCSD (San Diego, CA)
U. New Mexico (Albuquerque, NM)
Washington (Seattle, WA)
Wisconsin (Madison, WI)

Russia

Ioffe (St. Petersburg, Russia)
Keldysh (Udmurtia, Moscow, Russia)
Kurchatov (Moscow, Russia)
Moscow State (Moscow, Russia)
Triniti (Troitsk, Russia)
Gycom (Nizhny Novgorod, Russia)

European Community

Cadarache (St. Paul-lez, Durance, France)
Consorzia RFX (Padua, Italy)
Culham (Culham, Oxfordshire, England)
Frascati (Frascati, Lazio, Italy)
FOM (Utrecht, The Netherlands)
IPP (Garching, Greifswald, Germany)
JET-EFDA (Oxfordshire, England)
KFA (Julich, Germany)
Kharkov IPT, (Ukraine)
Lausanne (Lausanne, Switzerland)
Chalmers U. (Goteberg, Sweden)
Helsinki U. (Helsinki, Finland)
U. Naples (Naples, Italy)
U. Strathclyde (Glasgow, Scotland)
U. Wales (Wales)

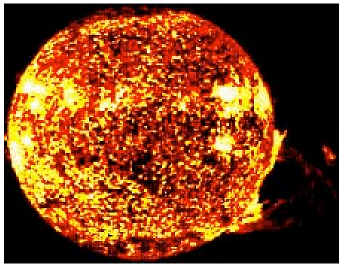
Japan

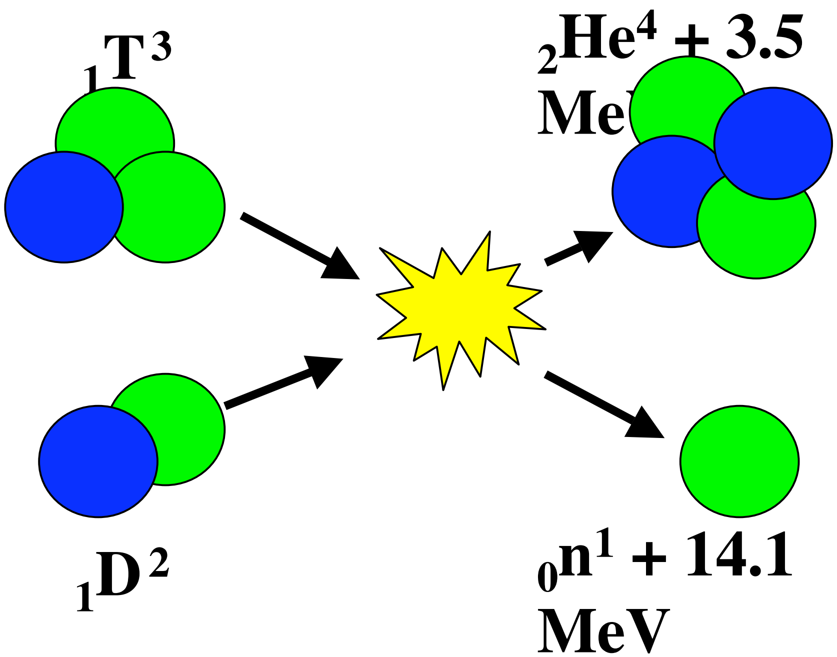
JAERI (Naka, Ibaraki-ken, Japan)
JT-60U
JFT-2M
Tsukuba University (Tsukuba, Japan)
NIFS (Toki, Gifu-ken, Japan)
LHD

Other International

Australia National U. (Canberra, AU)
ASIPP (Hefei, China)
KAIST (Daegon, S. Korea)
KBSI (Daegon, S. Korea)
National U. (Taiwan)
Nat. Nucl. Ctr. (Kurchatov City, Kazakhstan)
SWIP (Chengdu, China)
U. Alberta (Alberta, Canada)
U. of Kiel (Kiel, Germany)
U. Toronto (Toronto, Canada)

THE FUSION REACTION POWERS THE STARS AND PRODUCES THE ELEMENTS OF THE PERIODIC TABLE





- For 50 years worldwide, teams have been trying to exploit the fusion reaction as a practical energy source

- The promise is for an environmentally friendly method for generating electricity with an inexhaustible fuel supply

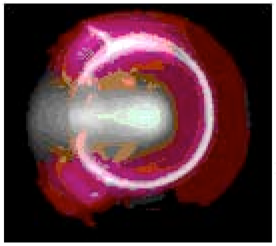
THE FUSION REACTION ELASTIC SCATTERING CURVES LEAD US TO THE STUDY OF CONFINED PLASMAS

- Even at the optimum energy, the nuclei are much more likely to scatter elastically than to fuse

- Nuclei must be confined for many interaction times

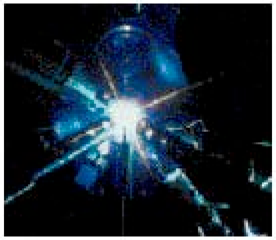
- Multiple scatterings thermalize the constituent particles

- At the energies involved (10 - 100 keV), matter becomes full ionized = plasma

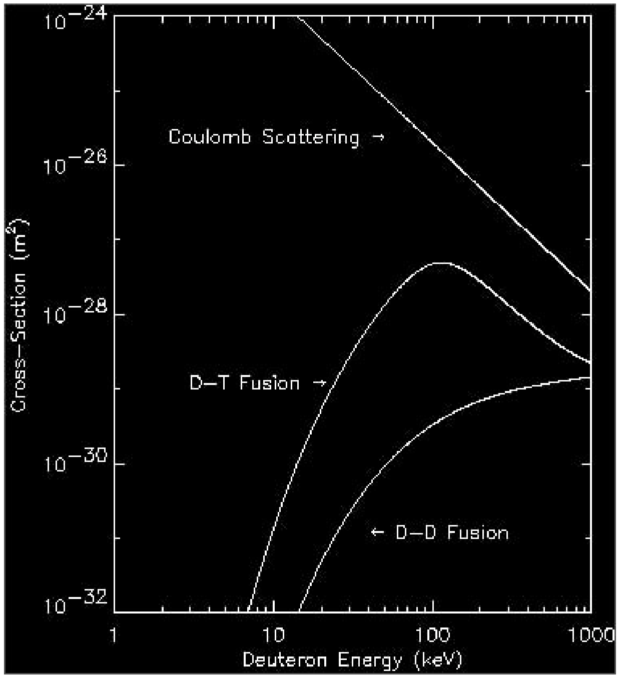


Magnetic Confinement

Inertial Confinement



Gravity



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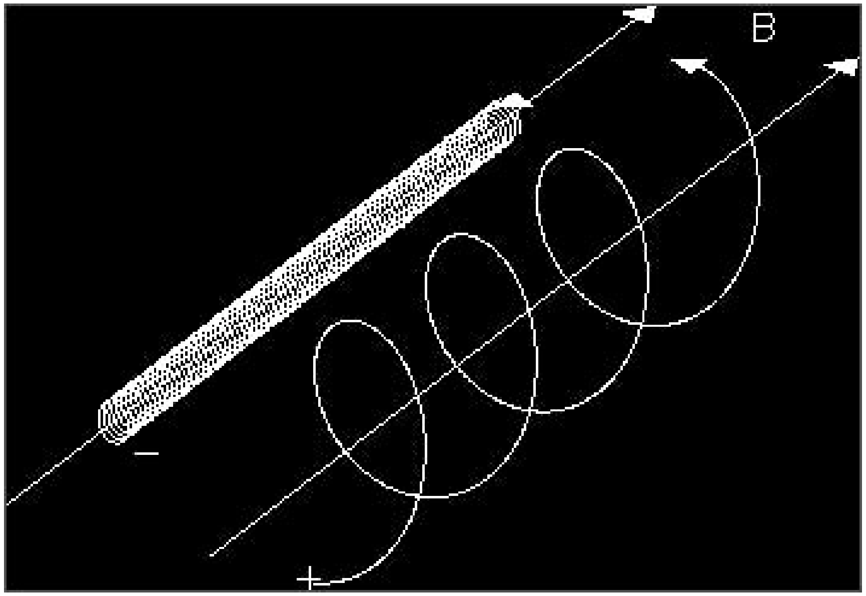
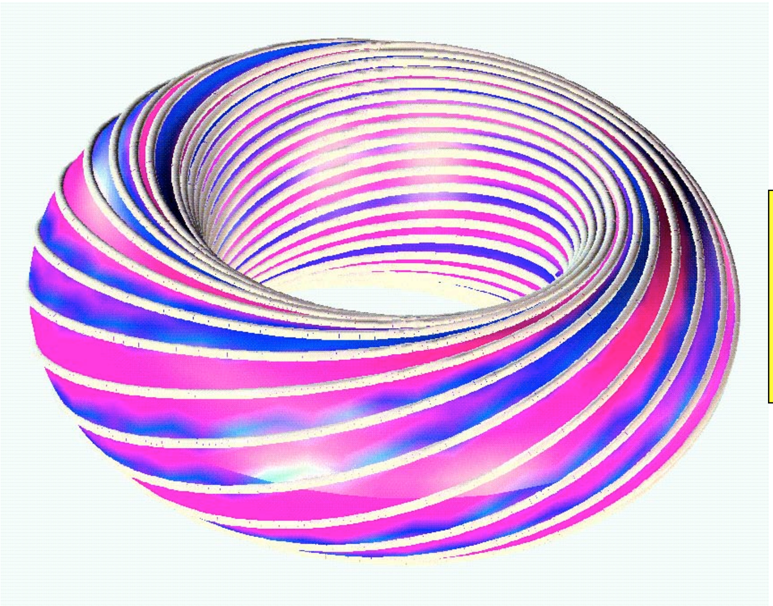
MAGNETIC CONFINEMENT - IONIZED PARTICLES ARE BENT BY THE LORENTZ FORCE INTO CIRCULAR ORBITS

In the simple example shown, there is no confinement at all parallel to the magnetic field





For a practical device, the end losses must be eliminated

FUSION RESEARCH PRESENTS MANY CHALLENGES

- Development of physical models for plasma stability and transport
  - 3D motion, wide range of space & time, free energy driven turbulence
- Design large experiments
  - 3D coupling of electromagnetics, structures, heat transfer, neutronics
- Development of complex diagnostics
- Development of plasma heating and fueling methods
- Acquisition, analysis, display and interpretation of large quantities of experimental data
- All of these are computationally intensive - thus network intensive in a collaborative environment

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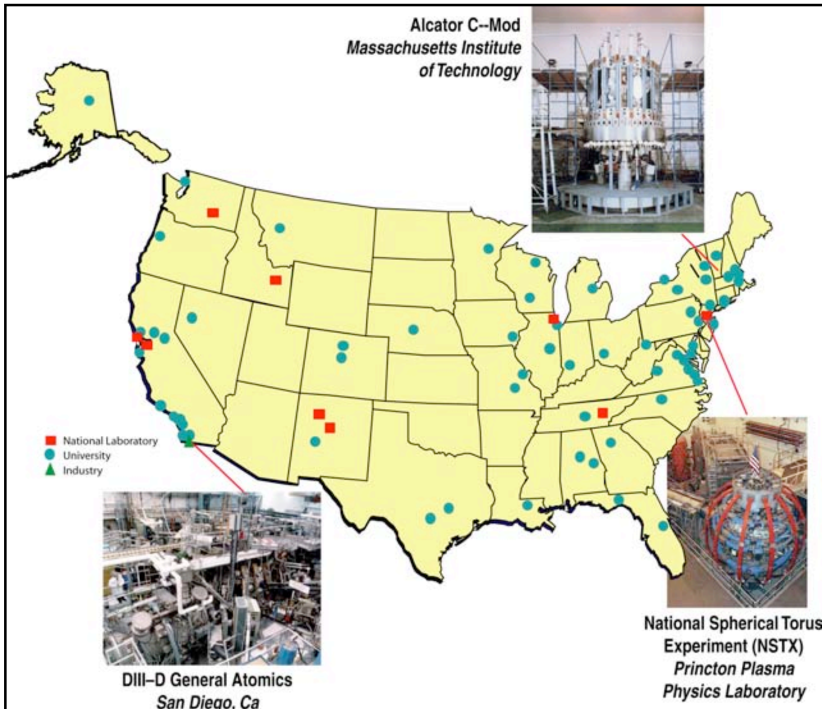
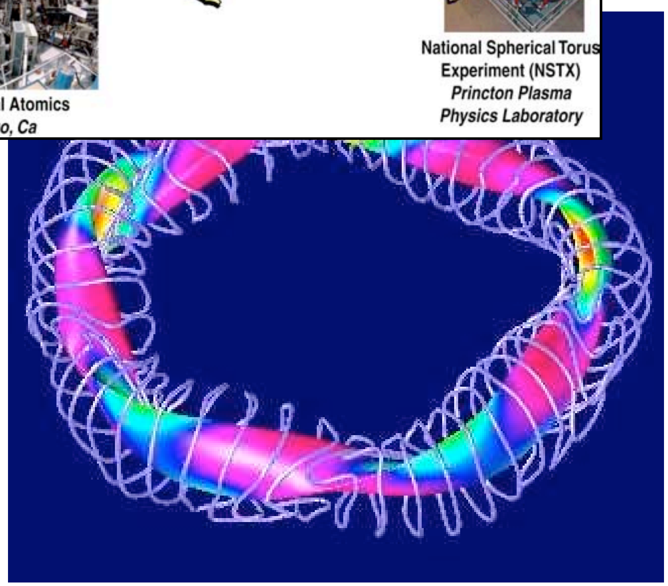
THREE LARGE U.S. EXPERIMENTAL FACILITIES AND A VIBRANT THEORETICAL COMMUNITY

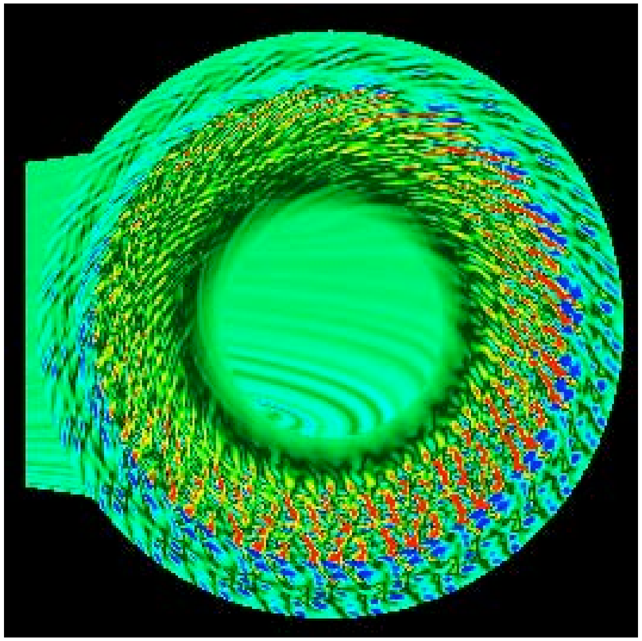




- 3 Large Experimental Facilities
  - ~$1B replacement cost
- 67 U.S. fusion research sites
  - Over 1500 scientists
- Efficient collaboration is required!
  - Integrate geographically diverse teams
- Network is critical

FUSION ENERGY SCIENCE IS A COMPUTATIONAL GRAND CHALLENGE

- Many body problem with closed solution not possible
- Vast range in space and time which can span over 10 decades
- Turbulence
- Extreme anisotropy
- Interaction of fine-scale kinetic physics & large-scale fluid-like physics
- Overlap in scales often means that strong ordering is not possible



EXPERIMENTAL SCIENCES PLACES A LARGE PREMIUM ON RAPID DATA ANALYSIS IN NEAR-REAL-TIME

DIII-D Control Room

- Test physics & extend performance
  - Pulsed: 10s duration plasma/20 minutes
- 20-40 people in control room
  - More from remote locations
- 10,000 separate measurements/plasma
  - kHz to MHZ sample rates
  - Between pulse analysis

- Not batch analysis and not a needle in a haystack problem
  - Rapid "real-time" analysis of many measurements
  - On the order of 1 GB per plasma pulse
- More informed decisions result in better experiments
  - The collaborative control room

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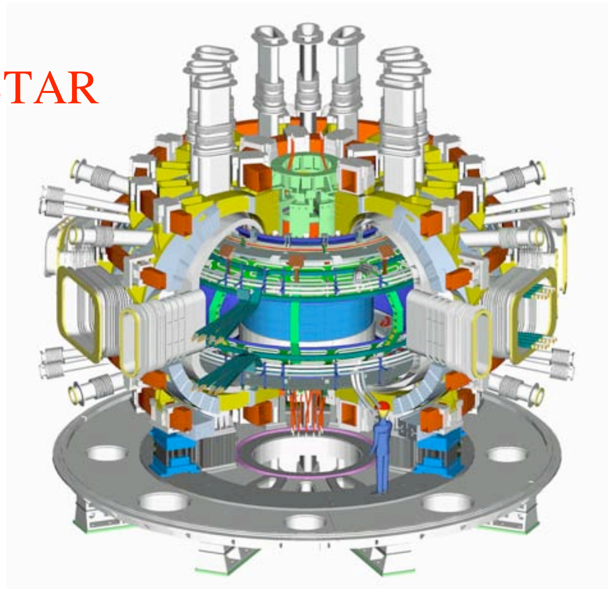
NATURE OF FUSION RESEARCH DRIVES REQUIREMENTS FOR COMPUTING AND NETWORKING

- Experiments
  - Real time interactions of large, geographically extended teams
  - Real time interactions between specialized small groups
  - Faster between-pulse analysis translates directly to productivity
  - Building an extended team of experts from small groups
  - Barriers to use of powerful analysis tools can be significant

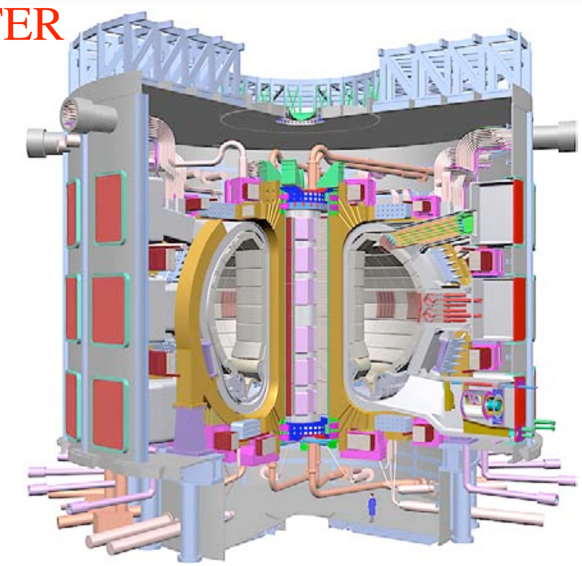
- Theory and Computation
  - Simulations producing very large data sets (GB=>TB=>PB)
  - Interactive visualization and analysis presents a severe challenge for computing and networking
  - Increased code sharing and collaborative development
  - Real time interactions of geographically extended teams

NEXT LARGE DEVICES WILL NOT BE IN THE US

KSTAR

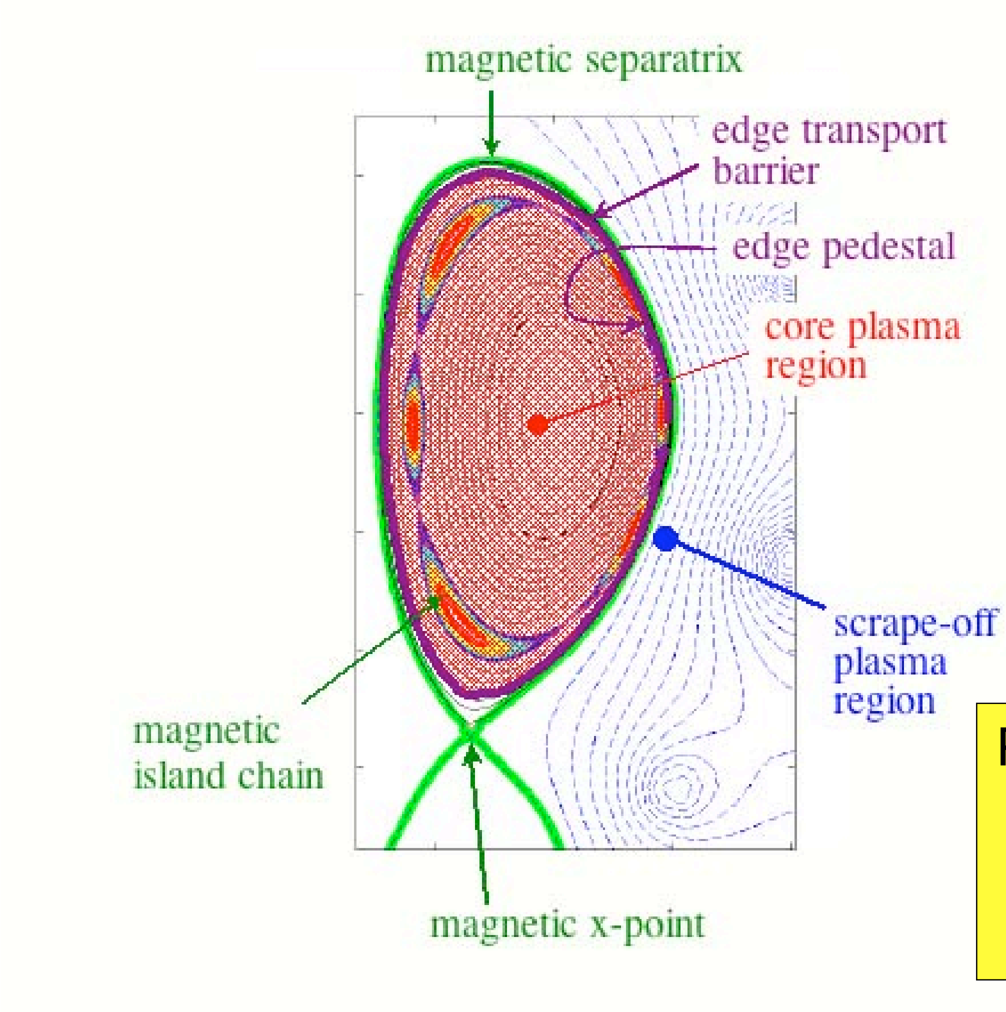


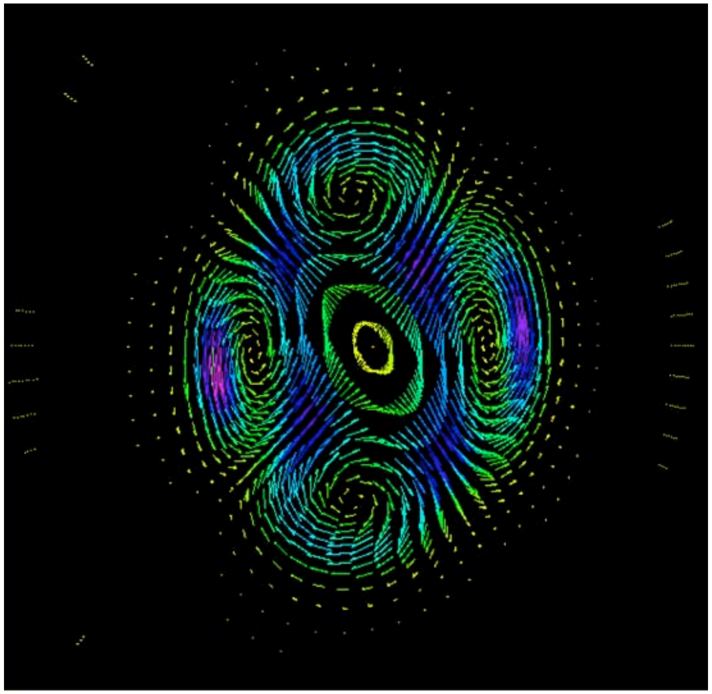
ITER



- One physical location
  - International collaboration
- Pulsed experiment with simulations
  - ~TBs of data in 30 minutes
- Successful operation requires
  - Large simulations, shared visualization, decisions back to the control room
  - Remote Collaboration via FusionGrid
- Successful construction phase
  - Share CAD archives (TBs)
- Network is critical
  - IPV6?

FUSION SIMULATION PROJECT (FSP): INTEGRATED SIMULATION & OPTIMIZATION OF FUSION SYSTEMS





Program Goals:
- Comprehensive models
- Architecture for integration
- Computational infrastructure

REMOTE LEADERSHIP OF THE JET TOKAMAK IN ENGLAND FROM SAN DIEGO USING RP TECHNOLOGY

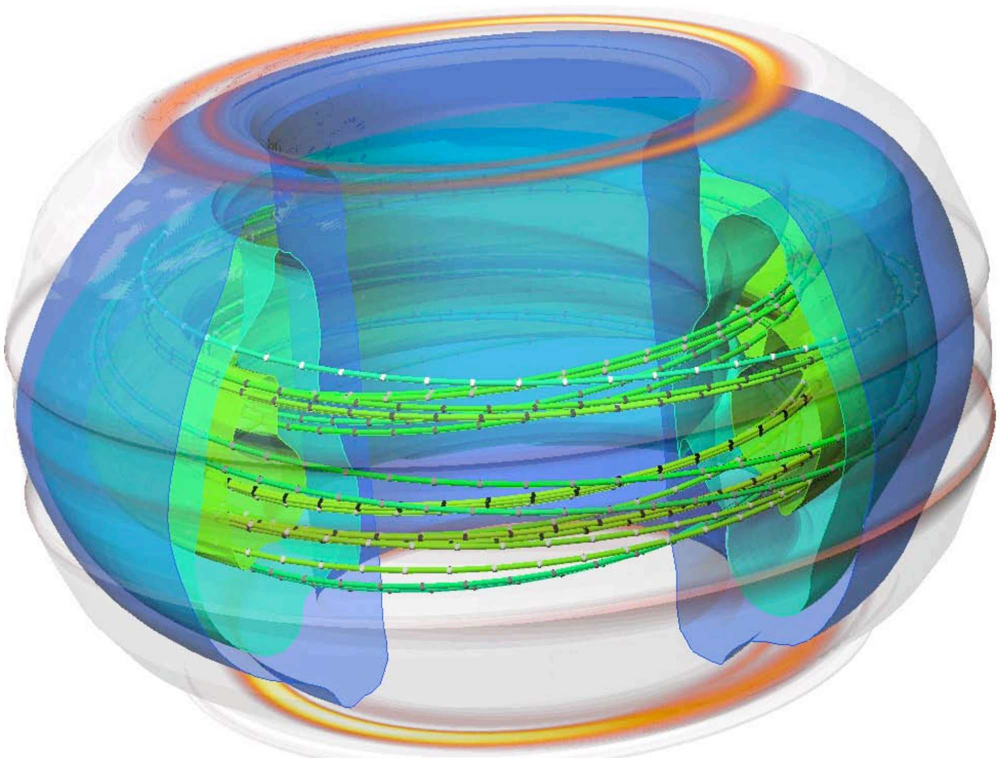
January 2004, San Diego

FusionGRID
www.fusiongrid.org

It is becoming more common:
Japan - US, US - Germany, & EFDA–JET

LARGE SCALE SIMULATIONS, DATA MANAGEMENT & VISUALIZATIONFOR BETTER UNDERSTANDING

- To facilitate quantitative comparison of simulations & experimental results



SciDAC CEMM NIMROD Simulation of a DIII-D Plasma

FusionGRID
www.fusiongrid.org

Raising the challenge of very large datasets
- MDSplus
- Storage method
- Data location
- Parallel I/O

ADVANCED RESERVATION COMPUTATION FOR DATA ANALYSIS TO SUPPORT EXPERIMENTAL SCIENCE

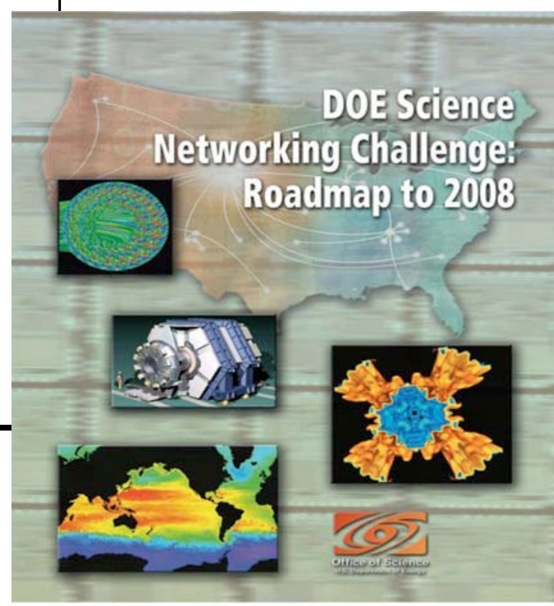
- Long-term vision: SciDAC code on supercomputer between pulses
  - Data management
  - Network QoS
  - Visualization
  - CPU scheduling
  - Faster CPUs and algorithms

- End-to-end agreement being prototyped in the NFC project
  - CPU reservation
  - Network transfer agreements based on simple prediction

- Has the potential to greatly impact the quality of experimental science

TABLE 2.1: SCIENCE DATA NETWORK & COLLAB DRIVERS

1995 - 1999	2002 - 2004	2007 - 2009
Research at DOE's three main tokamak facilities, GA, MIT, & PPPL, & numerical simulations generated 2 TB of data in 1998 (mostly experiments)	Present plasma physics/fusion experiments and simulations are generating 20 TB/year of data (split 50-50)	Driven mainly by large scale advanced simulations and preparation for a burning plasma experiment, fusion researchers will be generating 1 PB/year of data by 2008. Collaborative tools are needed to be full partners in the international program.



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NETWORK SERVICES ARE REQUIRED

- Successful sharing of distributed resources for collaboration
  - Computers, data, instruments - Grid
  - Challenge: real-time interactions among large experimental teams, the requirement for interactive visualization, processing of very large simulation data sets
  - Shared tools and solutions are valuable so as to reduce the n x m interactions to a more tractable scale

- The conflicting requirements of transparency and security
  - Central management of PKI or equivalent technologies
  - Include international collaborators

- Global directory and naming services
  - Distributed computing services for queuing and monitoring

- Guaranteed bandwidth at particular times or with certain characteristics

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CONCLUDING COMMENTS

- Collaborative technology critical to the success of the FES program
  - Experimental: Fewer, larger machines in future (ITER, KSTAR)
  - Computation: Moving toward integrated simulation (FSP)

- Network requirements are demanding and critical
  - Both size of datasets and provided services

- The US can lead by example in fusion networking
  - Opportunity for a development project and a demonstrated capability that might allow the US to take a major lead in the future worldwide fusion networking requirments

> *First on our list is fusion. The prospect of limitless source of clean energy for the world leads with our commitment to join the international fusion energy experiment known as ITER.*
> – Secretary of Energy Spencer Abraham, November 10, 2003
> Introducing the Department's 20-year plan for building the scientific facilities of the future.

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